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STRENGTH, COST, CAPABILITIES, AND REQUIREMENTS OF GERMAN GROUND DEFENSES AGAINST AIR ATTACK

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STRENGTH, COST, CAPABILITIES, AND REQUIREMENTS OF GERMAN GROUND-DEFENSES AGAINST AIR ATTACK

I. SUMMARY AND CONCLUSIONS

Particular importance attaches to the German ground-defenses against Allied bombings, in view of the mounting intensity of attack and the concerted Allied efforts to reduce defensive fighter-opposition through damage to aircraft factories and destruction of fighters in the air. The following conclusions may be drawn as to the strength, cost, and capabilities of these ground defenses, together with their implications for future United Nations bombing operations against European targets:

1. German ground-defenses are organized into a well-knit system within the German Air Force with full cooperation among all weapons. The defenses have been strengthened over a considerable period of time, and all important cities and industrial targets are well-protected by Flak and searchlight installations. Smoke screens and balloon barrages are increasingly being used.

2. Present holdings of anti-aircraft artillery are variously estimated at nine to thirteen thousand heavy guns and thirty to fifty-five thousand light and medium guns, of which 75 percent are used to defend cities and the remainder on active military fronts.

3. Of heavy guns (effective at maximum altitudes of present raids), the 88mm. dual-purpose anti-aircraft and anti-tank gun is the most important, followed by the 105 mm. gun. The 20mm. and 37mm. guns are the chief light weapons. Altitudes at which Flak is effective appear to be increasing

faster than the operational ceilings of Allied bombers, but accuracy decreases rapidly with altitude. (Chances of damage to aircraft at 10,000 feet are five times as great as at 20,000 feet, and fifteen times as great as at 30,000 feet.) Radio detection and radio fire control apparatus are being more and more extensively employed.

4. Artillery fire alone is not likely to make the cost of future bombing operations prohibitive. Direct losses through Flak have not been high, probably less than 1 or 2 percent for RAF and USAAF operations. Damage to aircraft, frequently making them easy prey for enemy fighters, is more serious; in the first six months of 1943, 20 percent of American daylight bombers over enemy targets were damaged by Flak.

5. Of even greater importance than damage or destruction of bombers are the deterrent functions performed by ground defenses. Bombers are forced to fly at maximum ceilings, adding to the already complex navigational problems; searchlights and smoke screens conceal targets and confuse crews; the presence of Flak and searchlights in strength requires circuitous routes to and from the target, brief bombing runs, and less favorable approaches; all of these factors substantially reduce the effectiveness of operations. In addition, balloon barrages frequently prevent low-level attacks.

6. Evasive tactics, including changes in course and altitude at irregular intervals, have been developed. The "saturation" tactics of RAF night bombers, concentrating a heavy weight of attack in a very brief period of time, have been effective in minimizing overall Flak risk. Heavy American daylight attacks are usually conducted at maximum altitudes ~~where~~

where danger from Flak is slightest, although attacks at minimum levels have also been successful.

7. The considerable economic cost to Germany of maintaining ground-defenses includes the commitment of some 750,000 regular GAF Flak personnel to the defense of European cities, an expenditure of able-bodied manpower which Germany can ill afford. To this must be added the skilled labor occupied in the AA-artillery industry. Use of industrial facilities for defense equipment precludes their use for other war production; this is especially important in the radio industry. The requirements for raw materials (steel, copper, and nickel) are not believed to be of marked significance.

8. German defensive requirements, relative to the weight and intensity of Allied attack and the extent of the area to be defended, are increasing. Allied acquisition of airfields in Italy, and reductions in German fighter strength will place an even greater burden on these defenses.

9. Total AA-gun holdings are the cumulative result of several years' production. Present monthly output is believed, for this reason, to make only a relatively slight contribution to gun deployment and defensive opposition. There are evidences that the defensive position may be becoming somewhat strained, particularly in the supply of ammunition.

10. The limitations to a further expansion of anti-aircraft defenses, in the face of increasing requirements, are probably set by a shortage of ammunition parts, particularly fuses, and by a shortage of trained operating personnel to man the guns. Additional operating personnel can be made available by the further use of civilians below and above combat age and

possibly women, but only at a sacrifice in accuracy of fire. Fuse supply may prove to be the ultimate limiting factor, in view of the rapid turn-over in ammunition, greatly increased requirements which Germany may not have anticipated, and the possibility that German and Swiss manufacturers may now be operating at full capacity. This suggests the advisability of a further investigation of the Axis fuse industry as a possible bombardment target.

11. German defensive capabilities certainly cannot increase as rapidly as the stepped-up scale of Allied offensive air operations would require. There is still no reason to doubt, however, that the German ground-defenses will continue to provide considerable opposition to American and British bombing raids.

II. INTRODUCTION

The ever-increasing tempo of Allied bombing assaults on the European Axis economic and military structure has focussed attention on German defensive capabilities against aerial attack. These capabilities comprise extensive and well-developed systems both of night and day fighters and of ground anti-aircraft defenses. With the determined effort to eliminate German fighter-strength both by the destruction of GAF fighters in the air and by attacks on fighter-production facilities, increasing importance is attached to the role of the active ground defenses. It is proposed in this report to evaluate these German ground-defenses protecting Axis cities, industries, and military installations, from the standpoint of defensive capabilities and requirements, and economic costs to the enemy.

The history of military-weapon development suggests that the introduction of new offensive weapons or tactics has always been met with strenuous efforts to develop effective defensive counter-weapons. The advantage of the initiative rests with the offensive. As a result, offensive weapons hold sway during the time-period necessary to perfect defensive weapons to neutralize them. The relative success in this war of offensive bomber operations and the purely defensive anti-aircraft system (artillery, searchlights, and balloons) supports this general observation. German ground-defenses in themselves have never been sufficiently effective to make day or night bombings prohibitive in cost. The original advantage which accrued to aerial operations earlier in the war, however, has since been reduced by improvements in defensive AA weapons. It should not be implied, moreover, that these ground defenses have not played a valuable role both in destroying attacking planes and in decreasing the effectiveness of Allied bombing operations.

The primary function of the German ground-defenses is not to destroy planes. More properly defined, it is to vitiate the success of bombing missions by all possible means. An evaluation of the effectiveness of the defensive system, therefore, cannot rest solely on the numbers of aircraft destroyed or damaged by Flak alone, or by Flak in conjunction with fighters. Anti-aircraft defenses perform valuable deterrent functions in forcing aircraft to operate at maximum altitudes unfavorable to accurate bombing, in dazzling pilots and obscuring target areas to hamper navigation and prevent identification of specific objectives, and otherwise in reducing the accuracy and effectiveness of bombing.

Anti-aircraft artillery (Flak) constitutes the backbone of the elaborate German ground-defense system. All major targets in Axis Europe within striking range of Allied bombers may be expected to be well-defended by both heavy and light guns. Searchlights provide an invaluable supplement in night defenses, in cooperation with Flak and night fighters and as an independent deterrent. Balloon barrages and smoke screens, employed on a lesser scale, form adjuncts to the regular Flak and searchlight defonses.

III. GERMAN DEFENSIVE CAPABILITIES AGAINST AERIAL ATTACK

A. Organization of the Ground-Defense System

Primary responsibility for defensive measures against enemy bombing raids lies with the German Air Force. Greater Germany and the occupied territories are organized for defensive purposes into Air Districts or "Luftgaue". Each "Luftgau" is responsible for all defenses - Flak, fighters, warning system, searchlights, and balloons, as well as for the Air Raid Protection system within its territory. The commander of the Luftgau is subject to the authority of the Chief of the Air Forces alone. The permanent Flak defenses within the Luftgau are controlled directly or through Air Defense Commands organized in important industrial areas. A centralized system controls all Flak batteries, and the battalions, sub-groups and groups into which they are organized, and to relay information on aircraft movements, order barrage fire, and control cooperation with fighter and other defenses within the area.

The German air-raid-warning system is fed by information from numerous listening posts throughout the occupied countries, most of which probably use Radio Detection Finding (RDF) equipment. These radar devices

consist of long-range "Freya" apparatus for preliminary detection without measurement of altitude and short-range "Wuerzburg" apparatus for accurate tracking of the aircraft. In some cases, the aircraft reporting system is combined with the Ground Control Interceptor stations for night fighters, which also use this radio equipment.

The maximum effective distance of the "Freya" is reported to be some 150 to 175 miles. It is claimed that the Germans have a chain of Freya stations along the coast from Norway to Southern France, placed at intervals of less than 70 miles. Large and small Wuerzburg apparatus, with ranges of 40 and 25 miles respectively, follow the course and speed of the aircraft once it is over German-held territory. Wuerzburg apparatus is also located along the coastal frontier.

As soon as the bombers are detected by the warning system, while yet a considerable distance from their objectives, the Luftgaue toward which they are flying receive a preliminary alarm: all noticeable factory lights are extinguished, radio stations go off the air, and crews of the AA guns and searchlights prepare for action. When it becomes evident towards which district the bombers are flying, a second state of alarm is declared: sirens are sounded, civilians go to the air raid shelters and AA crews are put in readiness. The Luftgau is placed in the third state of alarm when the enemy planes are actually overhead.

B. German Ground-Defense Weapons and Equipment

Developments in German anti-aircraft weapons have resulted from a lengthy program of research and experimentation. The Spanish Civil War and the Polish and French campaigns provided valuable proving grounds for new

weapons and tactics. As a result, the intensive program of aerial bombardment of Axis cities found the Germans with efficient and relatively standardized equipment. Improvements made in the last few years have been largely in the field of rradio detection and radio fire-control equipment and in refinements in existing types, rather than in the incorporation of new gun models into the defense system.

1. Anti-aircraft Artillery. German AA artillery has been designed to serve a dual anti-aircraft and anti-tank role, and has been frequently used for ground attack pruposes as well. Rapid mobility, high muzzle-velocity, and a high rate of fire have been stressed in all gun models.

The backbone of the "heavy" Flak equipment is the 88 mm. dual-purpose gun, which comprises an estimated 65 percent of total heavy AA gun holdings. The 105 mm. gun, now being produced on a high priority rating, constitutes an additional 20 percent. The remainder of the heavy Flak defenses are composed of 128 mm. guns, 75 mm. AA/AT guns, and 150 mm. static defense AA guns of which relatively little is known as yet. Table 1 on the following page gives the relevant data on performance for these gun types.

Heavy AA guns fire high explosive shells set with a time fuse which detonates the projectile at the end of a predicted time of flight. The "effective" ceilings of heavy German Flak, defined as the maximum altitude at which the most frequently used fire control method, "continuous following", can be carried out, are listed below. Barrage fire can be carried out at higher altitudes, up to the fuse ceilings shown in Table 1.

75 mm.	25,000 ft. (est.)
88 mm.	26,250 ft.
105 mm.	31,000 ft.
128 mm.	32,000 ft. (est.)
150 mm.	37,000 ft. (est.)

Table 1. PERFORMANCE DATA FOR
GERMAN AA GUNS AND AUTOMATIC WEAPONS

Gun mm.	Gun inches	Muzzle Velocity ft/sec	Weight of Projectile lbs	Practical rate of fire, rounds/min.	Maximum vertical range ft	Fuse ceiling ft	Effective ceiling ft	Lethal radius burst ft
HEAVY								
150	5.91	3450	88.6	6/8	66,000	40/45,000	(37,000)g	75
128	5.00	2500	55.0	8	42,600	35/40,000	(32,000)g	(60)
105	4.14	2890	32.2	8/10	41,300	37,000k	31,000 g	50
		2690	19.8					
88	3.46	2735	20.2	15	35,700	32,500k	26,250g	30
75	2.95	2780		15	37,000	30,000k	(25,000)g	
LIGHT								
50	1.97			15		18,000	10,000 f	
47	1.85	2620		40/60	22,300	17,000	8,000 f	
40	1.57	2950	2.2	80	23,200	16,200	6,000 f	
37	1.45	2690	1.4	60	15,600	13,775 j	5,000 f	
20	0.79	2950	0.253	120/200	12,465	7,215 h	3,500 f	
MACHINE GUNS				(500)e		(2,400)c		
7.92	0.31	(2600)		(125)d	8,543	(3,000)b	2,400 a	
RIFLE								
7.92	0.31	(2600)		--	---	---	(1,500)a	

( ) Estimated
a Effective Slant Range
b Limit of tracer, slant
c Limit of observed fire, slant
d For long periods of fire
e For short bursts up to 100 shots with cool gun.
f Max. vertical height for accurate engagement.
g Effective ceiling for 20 sec. engagement of directly approaching 300 mi/hr plane.
h Self destroying 6 sec.
j " " 14 sec.
k Max. ceiling for predicted concentration (single bursts).

SOURCE: Headquarters, VIII Bomber Command, Anti-aircraft Memorandum No. 4.

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Accuracy at these ceilings, however, is very much less than for lower altitudes of fire. A new version of the 88 mm. gun has been reported, with an effective ceiling considerably higher than that of any heavy AA artillery now in existence. The effective ceilings for the main defensive weapons now in use, the 88 mm. and 105 mm., of 26,250 ft. and 31,000 ft. are as high or higher than the maximum altitudes at which USAAF planes are now bombing. RAF night raids are generally conducted at considerably lower altitudes.

German light-Flak weapons have a higher rate of fire and employ high explosive shells with percussion fuses, together with tracer, which are self-destroying. The instantaneous fuse means that a direct hit is required before the shell is effective. The 20 mm. AA/AT, of which there are both single and quadruple-mounted models, is the main light Flak weapon. Some 70 percent of the automatic (light) weapons are of this type; 37 mm. guns comprise an additional 20 percent. Both 40 mm. and 50 mm. light or medium Flak guns are also part of German AA equipment, but are not extensively used.

The 20 mm. and 37 mm. guns are effective up to ceilings of 3,500 feet and 5,000 feet, respectively. Above these altitudes, defense of the skies depends on heavy Flak. The light AA weapons are deployed in defensive positions in and around German cities as protection against low or medium level bombing attacks or against strafing of heavy gun positions.

2. Searchlights. German searchlight equipment dates from the First World War. At present, two main types of searchlight are in use: a standard 150cm. heavy searchlight, operating with sound or radio locator, optical director and generator, and a smaller searchlight of 60cm., using only a generator. Some searchlights of 200cm. and larger have been developed,

but little is known of their strength at present. The 150 cm. searchlight is effective to a height of 13 to 16,500 feet in favorable weather. Later models of this searchlight may be in use up to altitudes of 20,000 feet or more. The 60cm., designed for use against low-flying targets, extends to 5,000 feet under favorable weather conditions.

3. Barrage Balloons and Smoke Screens. Balloons appeared over a few German cities at the outset of the war, but apparently only came into more considerable use when German pilots brought back reports of the effectiveness of British and Russian balloon defenses. Two types of barrage balloons were known to exist in Germany at the beginning of World War II, one inflated with hydrogen gas and the other with both hydrogen gas and air. Since that time, intelligence reports have mentioned various new types of balloons and balloon equipment.

Smoke generators, employed both on shore and on coastal vessels in harbors and rivers, have come recently into more widespread use to provide smoke screens over important German cities and industrial areas.

C. Tactical Employment of the Equipment

1. AA Artillery. The enemy's Flak defenses perform a number of complementary functions in impeding bombing attacks, the most important of which include: (1) destroying attacking aircraft; (2) damaging planes so that they lose formation and, as stragglers, become easy victims of fighter aircraft; (3) breaking up tight formations of bombers to simplify the tast of the fighters; (4) setting up deterrent barrages which prevent aircraft from penetrating to their objective; (5) forcing attacking bombers to fly circuitous routes to avoid areas of gun concentrations, thereby adding to the

already complex navigational problems and reducing bomb-carrying capacity; (6) forcing enemy bombers to operate at maximum altitudes with a consequent loss in aircraft performance, increase in navigational difficulties and reduction in bombing accuracy due to inability to identify ground features for visual pinpointing; and (7) submitting planes to heavy fire during the bombing run, thereby disturbing bombing aim and preventing the use of certain typesof bombsights now in use.

For these functions, guns and related equipment with a high rate of fire are required, as well as rapid fire-control calculations, fast tracking-speeds and a high muzzle-velocity.

a. Artillery-fire control. The fundamental fire control problem of the AA gun is, first, to obtain data on the elevation, speed, and course of the attacking plane, by the use of optical sights or radio-detection equipment. The future position of the plane is then predicted by the use of a mechanical director or by plotting. Finally, a shell must be fired at the predicted position so that the plane and the shell arrive at this position at the same instant. With heavy gun fire, the shell is fused to explode at this future predicted position; with automatic weapons the shell explodes on contact with the aircraft.

Three methods of controlling the fire of heavy-gun emplacements are normally employed by the Germans: continuously pointed fire, predicted concentrations, and barrages. In the first method, each gun battery follows the target independently. Range and height finders, or else radio equipment, provide continuous data on the altitude and speed of the enemy plane; computations on these data are performed mechanically by the director,

which then provides data on the future position of the plane to be transmitted electrically to the guns in the battery. The guns fire on the basis of the continuously varying data. This is the method used most frequently against USAAF daylight attacks and RAF night raids when data are obtained either by searchlights or radio detection.

Radio fire-control equipment, called "Flakmessgerat" (FMG) is being installed as rapidly as possible into all Flak batteries. Batteries employing this equipment are usually grouped into six-gun formations, rather than the usual four, to economize in its use. FMG measures range, bearing and elevation of the target aircraft by emitting a continuous succession of short radio pulses and observing the time taken for them to echo back individually from the aircraft. The latest Marks (or models) of FMG are sufficiently accurate to be used for continuous following, as well as other methods of fire control. Radio equipment, however, still does not generally provide as accurate data for fire control as does visual observation.

The second most favored method of fire control is predicted concentrations, which has recently come into very prominent use against VIIIth USAAF daylight bombings. This method involves a plot of the course of the enemy aircraft kept at a central control site. Future calculations are made for a predicted position of the plane, usually along the probable line of bombing approach. All gun batteries in the area are organized to fire salvoes simultaneously on this data.

Barrage fire is generally used when, because of heavy cloud or absence of searchlight illumination or radio equipment, either of the other

two fire-control methods becomes impossible. A fixed barrage is fired by all guns in the area into a sky volume or box along the course which the aircraft is expected to fly, usually just outside the expected bomb-release line. Guns fire at their maximum rate until the aircraft has left the box. This method results in an extravagant use of ammunition, and is rarely employed in daylight when other means of fire control are available. Heavy barrages have frequently been encountered by the RAF during night bomber missions.[1]

Fire-control equipment for light Flak weapons consists of a gunsight and a separate range finder. Guns fire independently, over the sight, without the use of predictors. Corrections in the fire are made by observation of the tracers.

b. Tactical Employment with Fighter-Defenses. Anti-aircraft guns further contribute to the destruction of enemy planes by a system of well-coordinated cooperation with night and day fighters. AA flares and signals are frequently used at night to indicate the position and course of enemy planes to friendly fighters in the vicinity. Night fighters use Identification Friend or Foe (IFF) radio equipment to avoid being fired upon by their own guns. On some occasions, the skies over the target area are divided into separate zones allocated either to the fighter of Flak defenses. In the recent raids on Berlin, ground fire was generally withheld to enable the night fighters to operate freely over the target area. Major assistance is also rendered the fighter defenses by Flak in damaging enemy bombers.

1. A further type of fire control, deterrent fire, is sometimes encountered at night; it involves cooperation with searchlights which operate through the use of sound locators.

These bombers become stragglers, and in daytime lose the advantages of their powerful defensive formations, thereby becoming easy prey for the fighter defenses.

2. Searchlights. Searchlights operate at night both as independent deterrent agents and as valuable parts of the Flak and fighter defenses. The renowned searchlight belt, which apparently existed exclusively for the aid of night fighters, has been abandoned and searchlights regrouped in clusters around probable approaches to the targets and in gun-defended areas.

The chief function of searchlights would appear to be the illumination of targets at night for more accurate predicted fire by the artillery defenses. Searchlight clusters, usually of from fifteen to thirty lights, although as many as fifty have been observed, are reported to be controlled by a powerful mater-light employing radio-detection or sound-location equipment. The other lights form a cone about the master light when it has picked up an enemy plane. Aircraft caught and held in the apex of this cone of lights have been subjected to intense Flak fire, all guns in the area concentrating on the targets thus illuminated. The cones are effective up to heights of at least 17,000 feet, and extremely effective at altitudes ranging from 5,000 feet to 15,000 feet. Searchlights also operate independent of the main clusters, to track enemy aircraft until they can be passed into a cone.

Searchlight cooperation with the night-fighter defenses consists principally of indicating the track of enemy aircraft to the fighters and of silhouetting the planes to make them more conspicuous targets. This

technique evidently reached a new refinement in the defense of Berlin against the large RAF raid of 23 August. On that occasion, the RAF lost fifty-seven bombers, primarily through cooperation between some twenty searchlights and huge swarms of night fighters.

The independent use of searchlights involves tactics of "dazzle" and "glare". Dazzle is the direct blinding effect of the searchlight rays on the bomber crew. This type of illumination, effective up to 15,000 feet when several beams are used, renders difficult the location of the target and accurate bombing, impairs night adaptation of eyes, thus permitting night fighters to appraoch unobserved, and has a pronounced psychological effect upon the crew. Glare tactics are used to greatest effect on nights of considerable ground or industrial haze. The searchlight projects a beam at a low angle of elevation, producing a pool of light over the target. This contributes to the problems of the bombardier and navigator by preventing visual identification of ground features.

3. Barrage Balloons and Smoke Screens. Unlike AA artillery and searchlights, which have a long record of development dating from the First World War, extensive use of balloons and smoke screens by the GAF is apparently a very recent development.

Germany was long skeptical of the usefulness of balloons as a deterrent to enemy aircraft. Barrages of these balloons undoubtedly have some psychological value, both as a bolster to civilian morale and as an added hazard to bombing pilots, particularly on cloudy days and at night. Beyond these uses, their chief function is to serve as a deterrent to low-altitude dive-bombing or medium-altitude level-bombing, as well as to cause

casualties among enemy aircraft. Balloons, when effective, oblige attacking bombers to operate at altitudes less favorable to accurate bombing.

The purpose of the balloon itself is to suspend a steel cable vertically in the air; the cable provides the real menace to enemy aircraft. The general requirements of the balloon, therefore, are sufficient strength to suspend the cable, and proper resistance to wind stress, etc.

Balloons were originally used solely for the defense of strategic industrial or military targets. They are now more in evidence around all important German cities. The altitude at which the balloons are flown and their disposition varies with the type of objective and the time of day or night. Although designed primarily against low-flying aircraft, balloons at altitudes above 7,000 feet are not uncommon. As early as October 1941, they were reliably reported at 12,000 feet, and their elevation has probably been increased since that time. The irregular layout pattern of the barrage usually employed is coordinated with light and heavy Flak defending the area, so that any gaps in the barrage are covered by the guns.

The first recorded use of smoke screens by the Germans occurred during the RAF night raids on the battle cruisers stationed at Brest. Since then the practice has been adopted more widely, largely in coastal areas. Smoke screens are employed primarily to obscure coastal landmarks, usually covering an area wider than the target itself to divert some of the bombs into the coastal waters. Generators on boats stationed in the harbor have been used to supplement the land installations. Experience indicates that smoke screen protection of inland targets is a more difficult job, since the screens themselves frequently act as landmarks. There is some indication

however, that smoke screen protection of strategic inland objectives is being undertaken.

D. Tactical Countermeasures to German Ground Defenses

A number of tactics to confuse and otherwise to evade the enemy's AA defenses, have resulted from a long period of study of RAF and USAAF bombing experiences. These tactics embrace both evasive action by individual aircraft and formation tactics by the bombing force as a whole.

The anti-aircraft artillery fire-control problem, as defined previously, consists of obtaining data on the elevation and course of the target aircraft, of predicting its future position by means of a director or plotter, and of firing a shell at this predicted position to arrive simultaneously with the plane. Effective gunfire, therefore, requires that the aircraft fly a steady course at constant speed and constant altitude from the original pick-up of the plane's position to the arrival of the shell at its later, predicted position. (Stated otherwise, the aircraft must maintain a constant course, speed and height for the period of prediction and the time of flight of the shell.) This total period is under ninety seconds in daylight, at maximum altitudes. At night, time of prediction is longer unless direct illumination is obtained, but the time of flight of the shell is usually less since the RAF operates at lower altitudes.

Evasive tactics which involve frequent changes in course and altitude, performed at irregular intervals so that no single course can be plotted, have therefore become the recommended procedure against predicted concentrations or continuous following methods of heavy-Flak fire-control. Low-level attacks make maximum use of the speed and maneuverability

of the plane in evading the light-Flak defenses. Extremely low altitudes of flight, with maximum use of cloud cover and land formations for concealment, have proved successful on many occasions since they provide the light-Flak with a rapidly moving target, limiting the time of engagement and making traversing difficult. Radio detection apparatus, moreover, cannot function for very low altitudes of flight.

A further principle which applies to American high altitude daylight raids is that accuracy of heavy Flak, as defined by the total chances of damage to the aircraft, decreases rapidly with increases in altitude. Bomber crews are instructed, therefore, to fly at maximum altitudes conforming with adequate plane-performance and bombing accuracy.

The RAF and USAAF have also developed evasive tactics for bomber formations to minimize casualties from AA fire. The Operational Research Committee of RAF Bomber Command has discovered that, both en route over land to the target and in the target area, concentration of planes in time and space, together with dispersion in height, will result in a minimum of aircraft casualties both by night and day. Studies have revealed that the Flak risks to a force of bombers cannot possibly be increased by flying in the closest formation. In a given area and time, the number of aircraft that can be engaged by searchlights and guns is limited by the number of guns, speed of prediction, and rate of fire. These limitations are greatest at night, when frequently only aircraft caught in searchlights cones are subjected to predicted fire. By passing concentrated streams of large numbers of aircraft over a given route, chances of any one aircraft being hit are correspondingly reduced. Dispersion of the formation in height creates

great difficulty in determining the exact course and height of a single aircraft, particularly when radio detection devices are used at night or during cloudy daylight conditions. This dispersion may consequently force reliance on barrage fire rather than more effective predicted methods of fire-control.

Actual experience of night bomber crews would appear to confirm these principles. Present RAF night bombing tactics, therefore, have devolved into attacks of heavy weight concentrated into very brief periods of time. The vast bombing force frequently spends less than an hour over the target. In this connection, it is worthy of note that RAF bomber crews have frequently reported AA fire to diminish during the course of the raid. While an explanation of this decrease is still incomplete, certain possibilities may be tentatively offered. As long as direct illumination with searchlights is available, guns can continue to fire at a limited number of planes. Greater numbers of planes over the target, while providing immunity for a larger percent of the bombing force, do not actually "saturate" the defenses. When FMG equipment is used, however, presence of aircraft in large numbers may completely confuse the radio pulses and consequently "swamp" or "saturate" the AA positions during the raid. Shortages of ammunition may also contribute to the decline in opposition, as may technical limitations such as possible overheating of the gun barrels.

In USAAF daylight operations, formation flying is requisite, both for protection against enemy fighters and for proper bomb-patterns on the target. Evasive action by the formation as a whole has followed the general

principles outlined above: formations are normally stepped-up in altitude when Flak is expected, to minimize Flak risks and create confusion from the differences in altitude; changes in course have also been adopted as an effective means of upsetting Flak prediction.

Other tactical countermeasures of lesser importance have been used occasionally. Flares have been found to create some confusion among searchlight batteries. Camouflage of the aircraft is believed to reduce chances of being detected visually. A partial answer to the balloon barranges has been developed in the form of cable cutters on the wing edges. Direct attacks on the balloons themselves has also proved effective.

E. Present Strength and Capabilities of German Ground Defenses

The German Air Force has long been impressed with the importance of AA weapons as a defense against aerial attack, for the protection of both troops in the field and rear -area installations and cities. Ground defenses around important cities and strategic objectives in Axis Europe already existed on a considerable scale when the RAF first undertook its major aerial offensive back in 1941. Since that time, all reports indicate that the ring of ground defenses around German-held cities has been strengthened. It is safe to say that all important cities, industrial targets, and military installations within range of Allied bombers are now defended by light and heavy AA guns, and frequently by searchlights, balloon barranges, and smoke screens, on an impressive scale.

1. Strength and Disposition of Equipment. Reliable estimates of the total strength of these defenses are difficult to obtain. A tentative OSS

statement[1] has placed total strength of the regular German Flak establishment at a maximum of 13,000 heavy guns, and 25,000 to 30,000 light and medium guns. This estimate is based largely on tables of organization of Flak units and British War Office reports on the number of such units identified. It is consequently subject to a considerable range of error. Two War Office reports of March 1943 place AA artillery strength at between 9,000 and 12,000 heavy guns and 30,000 to 55,000 light guns. The discrepancy between the OSS and War Office estimates of light Flak can be explained in part by the fact that the former does not include the Heimatflak (civilian AA units) which probably comprise largely light-Flak batteries. The War Office estimate places overall searchlight-strength at 15,000.

These strength estimates apply to the total Flak establishment, both at home and with the field forces. While Germany has stressed the use of AA guns in A/T and ground defense roles, the primary importance of this equipment in its anti-aircraft role has never been lost to view. Over three-fourths of the total Flak establishment is now believed to be deployed in Germany and Western Europe in defenses against Allied bombing raids.

Table 2 on the following page presents a sample list of the Flak and searchlight defenses of 26 German cities. It is based on photographic reconnaissance and reports of Flak opposition encountered during bombing raids. Many of the establishments listed are for the defenses existing a year ago, and in most cases have probably been increased in the

1. R and A Report No. 1020, 21 August 1943, "Strength and Disposition of German Anti-Aircraft Artillery".

Table 2. AA DEFENSES OF CITIES IN GREATER GERMANY

City	Date	Number of heavy guns	Number of light guns	Number of Searchlights
Germany				
Northwestern				
Hanover	Sept. 1942	100	100	75
Bremen	July 1943	274	294	82
Wilhelmshaven	Sept. 1942	70	125	35
Osnabruck	" "	20	45	12
Hamburg	" "	200	240	100
Kiel	" "	100	125	75
Emden	" "	50	75	30
Lübeck	" "	62	90	35
Western				
Essen	" "	100	60	35
Dortmund	" "	28	75	50
Munster	" "	40	60	30
Cologne	Feb. 1943	240	275	125
Dusseldorf	Sept. 1942	50	75	50
Duisberg	" "	40	30	25
Kassel	" "	28	60	15
Southwestern				
Frankfort A/M	Feb. 1943	120	120	50
Karlsruhe	Sept. 1942	24	60	20
Mannheim	" "	80	125	50
Friedrichshaven	July 1943	56	75	10
Saarbrucken	Sept. 1942	16	15	5
Central				
Berlin	" "	240	300	125
Rostock	" "	34	75	35
Stettin	" "	34	60	20
Nürnberg	" "	70	50	50
Augsburg	July 1943	84	75	50
Eastern				
Gdynia	Sept. 1942	24	36	9
26 cities in Germany		2,184	2,740	1,198

Source: AA Command Intelligence Summary, 15 Sept. 1942 and M.I. 14 AA Summary 291, July 1943.

interim. The Berlin defenses, for example, have been strengthened in anticipation of heavy bombings, and two hundred searchlights were reported in operation during the RAF raid of 23 August 1943.

German AA guns, even in "static" defense positions around German cities, preserve a high degree of mobility. Gun positions are frequently shifted after a raid, to confused attackers on subsequent raids. To the "static" defenses, moreover, must be added considerable numbers of railway Flak which are reportedly held in reserve around important cities and can be speedily transferred to supplement the defenses of other targets. The second raid on a German city frequently finds the AA defenses considerably strengthened. Flak guns mounted on Siebel ferries add a further measure of mobility to the AA defenses by providing supplementary defenses over wide coastal areas.

Important industrial installations (such as chemical works, aircraft assembly plants, ballbearing factories, synthetic rubber plants, etc.), operational airdromes and other strategic objectives are also provided with special Flak, searchlight and balloon defenses. Thus, the Goering Works near Braunschweig were reported in 1942 to have a defense consisting of forty-eight heavy and sixty light guns.

RAF and VIIIth USAAF bomber crews have been encountering balloon barrages and smoke screens more frequently on recent raids. Smoke screens employed over Brest on 16 April and Bremen on 13 June were very effective and seriously hindered USAAF precision bombing. Other coastal areas, such as Lorient, Wilhelmshaven, and Kiel, have also been provided with smoke screens. Specific industrial plants in the coastal area, such

as the Heinkel aircraft assembly works at Rostock and the Arado aircraft plant at Warnemunde, have been reported covered with smoke screens. It is becoming increasingly evident that this type of defense will become more important in future raids.

Deployment of balloon barrages is experiencing a similar increase, although it has not yet reached any extensive scale except over certain strategic bombing targets. Balloons have been reported in large numbers over industrial objectives in the Ruhr. Aircraft factories (such as Arado/Warnemunde) and submarine pens and dock areas at Lorient, Brest, Bremen, and elsewhere have been protected by barrages averaging from thirty to forty-five balloons and reaching a maximum of two hundred balloons at Brest while the battle cruisers were stationed there. Although there is no evidence of the use of balloons over Berlin, other major German cities such as Hamburg, Hannover, and Kassel have been provided with balloon protection.

2. Strength of Flak Personnel. OSS and British estimates coincide in placing regular officer and enlisted Flak personnel in the neighborhood of 900,000 to 1,000,000. Three-fourths of this total, or 750,000 men, would be assigned to duty in the defense of the Reich and Western Europe.

To this figure must be added some 100,000 to 300,000 men belonging to the "Heimatflak" (Home Flak). The Heimatflak is a German civilian AA defense organization for which recruitment began in earnest early in 1942. Heimatflak personnel consists of civilians who are trained to man the Flak guns in the neighborhood of their places of work during their spare time. Over-age civilians and those otherwise unfit for military

service comprise the majority of the Home Flak batteries, which are designed to relieve Air Force personnel for service elsewhere. In addition, a decree of February 1943 assigned youths of 16 and 17 into the Luftwaffe, for work in the AA defenses and other ground activities. Women have also been engaged in parts of the AA defense system. The introduction of this less-skilled personnel into the defense of important German cities such as Hamburg, Berlin, and Stuttgart suggests strongly that the maintenance of gun defenses at their present strength is causing a serious drain on available military manpower.

3. Opposition to Raids and Effectiveness of Defenses. RAF night bomber crews early in 1943 reported a general decline in both the intensity and the accuracy of enemy AA fire during the previous weeks of operations. This decrease was attributed to several factors, among them: (1) extension of the enemy's Flak responsibilities in former unoccupied France, Italy, and the Eastern Front, with a consequent dispersion of Flak resources; (2) conservation of ammunition; (3) employment of inexperienced Heimatflak personnel; (4) concentration of RAF night attacks, with possible "supersaturation" of the ground defenses; and (5) increased speed of RAF aircraft. The most reasonable of these explanations would appear to be the use of Heimatflak personnel, RAF tactics of concentration, and possibly conservation of ammunition. It is true that the defensive requirements of the GAF have increased, both because of the need to defend additional territory and because of the increasing intensity of Allied bombings. While Flak strength has probably not increased so rapidly as these defensive requirements, there is as yet no strong evidence that any appreciable reduction in deployment has taken place in Germany, the Low Countries, or France.

More recent reports of bomber losses, moreover, would seem to indicate that defensive opposition has stiffened. Raids in recent weeks on important industrial cities have met with strong AA, searchlight, and fighter opposition. RAF bomber losses have always been subject to wide variations, due to seasonal or random factors. The role of Flak and searchlights in destroying enemy planes, vis-a-vis the night and day fighter defenses, is extremely difficult to assess. For these reasons, any conclusions of trends on the relative strength and effectiveness of German ground defense opposition based on such short-term factors are bound to be unreliable.

Evidence of the relative strength of AA ground defense opposition is somewhat clearer for the VIIIth USAAF. While bomber losses were slight during the early raids on French territory, they have mounted sharply since the inception of the bombing program against Germany proper. Here again, the relative effectiveness of ground versus fighter defenses cannot be determined. It is clear, in any event, that 1943 daylight bombing missions against strategic French targets such as submarine pens, and against most German targets have frequently encountered intense heavy anti-aircraft fire. The following table indicates the number and percent of planes damaged (not destroyed) by AA fire in a few raids over French and German targets.

Target	How often attacked	No. of aircraft at target	Aircraft damaged	Percentage
St. Nazaire	5	446	192	43
Bremen	2	234	85	36
Vegesack	1	72	23	32
Hüls	1	137	32	23
Wilhelmshaven	6	501	85	17
Lorient	4	274	32	12
Kiel	2	230	12	5
Brest	1	48	nil	nil

Source: Headquarters, VIIIth Bomber Command, Anti-aircraft Memorandum No. 5.

Some absolute measure of the effectiveness of enemy AA fire in destroying and damaging Allied bombers can be gathered from VIIIth Bomber Command statistics. These figures, listed below, show that roughly 20 percent of the American bombers over all targets in 1943 have been damaged by enemy flak.

Month (1943)	No. of aircraft at target	Aircraft damaged by Flak	Percentage
January	246	74	30
February	227	74	33
March	588	58	10
April	325	54	17
May	890	142	16
June	662	133	20
Total	2,938	535	18.2

Source: Headquarters, VIIIth Bomber Command, Antiaircraft Memorandum No. 5.

Comparable figures for Flak damage to RAF night-raiders are not available. It is probable that they are not too dissimilar to the USAAF experience. Flak fire at night by "unseen" methods of fire control is far less effective than with direct or "seen" methods of fire control possible under good daylight conditions. But the present extensive use of searchlights at night contributes somewhat to a lessening of this disparity. Furthermore, American daylight bombings are considerably higher than the RAF, which render the bombers invulnerable to light or medium AA fire. Finally, the total chance of damage from heavy-Flak fire decreases rapidly as the altitude of flight increases, adding to the relative advantages of high altitude USAAF raids. The following figures from VIIIth Bomber Command show

that the total effectiveness (total chance of damage) of heavy Flak is over three times as great at 15,000 feet than at 25,000 feet.

Elevation feet	Total effectiveness (arbitrary units)
5,000	849
7,500	638
10,000	344
15,000	144
20,000	74
25,000	40
30,000	20

It is almost impossible to establish certainly whether an aircraft was destroyed by Flak or by fighters, or by a combination of both. The number of aircraft destroyed by Flak bursts alone, however, is probably very low - in the neighborhood of 1 to 2 percent on daylight raids, and less at night, as a very tentative guess. Many more bombers, however, are damaged by Flak and subsequently destroyed since they become easy targets for preying fighters.

Smoke screens have proved their usefulness on several occasions, particularly during daylight operations. USAAF crews reported that very effective smoke screens shielding the dock area of Brest and the city of Bremen, were serious obstacles to bombing accuracy. In view of these successes, deployment of smoke screens is likely to increase in the future.

Although balloon barrages are being established more widely, the effectiveness of this type of defense still appears to be limited. Balloons do serve as deterrents to low or medium level attacks on specific installations or small areas (coverage of wide areas requires a prohibitive number of balloons). The number of planes destroyed or damaged by balloons has

been slight, however, particularly because of the efficacy of cable-cutting devices.

IV. ECONOMIC COSTS TO GERMANY OF THE GROUND DEFENSE SYSTEM

A. Introduction

The elaborate network of radio-detection posts, AA guns and searchlights, smoke screens and balloon barrages which comprise the German ground defense system represent a major economic cost to the enemy. Expenditures of manpower, raw materials, and productive resources are involved in the manufacture of defensive equipment and the operation, maintenance, and repair of existing equipment, as well as in the replacement of expended ammunition and worn gun-barrels.

B. Manpower

Perhaps the greatest economic cost to Germany is the severe strain placed on the already tight manpower position. As indicated previously, some three-fourths of the 1,000,000 regular Air Force Flak personnel are tied down in the operation of AA guns used in the defense of German cities. (This does not include the 100,000 to 300,000 civilians in Heimatflak gun crews, or the large numbers involved in Air Raid Protection activities.) The supply of able-bodied manpower is virtually a fixed quantity in the German economic system, and one of its weakest links. The able-bodied GAF personnel committed to the ground defenses, therefore, is an expenditure of manpower which Germany can ill afford to make.

A considerable body of labor is employed in the manufacture, repair, and maintenance of ground defense equipment, and in the production

of Flak ammunition. Of greatest significance are the requirements for skilled labor used in the manufacture of gun barrels, breeches, and carriages, and in fire-control and fuse production.

C. Productive Facilities

Production of anti-aircraft artillery comprises a large proportion of total German artillery output. Although the German position in such facilities appears relatively comfortable, nevertheless, to the extent that much of the machinery and perhaps other equipment employed in this manner could be used in alternative types of war production, the requirements for ground defenses can be regarded as imposing a significant economic cost.

On the basis of very incomplete information, facilities now engaged in the production of fuses and optical fire-control instruments may have some important alternative uses for production of other scarce military items.

The manufacture of radio equipment of all kinds, on the other hand, has always been on the critical list of German industries. Radio-detection apparatus and radio fire-control equipment absorb a large portion of the output of radio equipment, and undoubtedly occupy facilities which could profitably be used for other military purposes within the industry.

D. Raw Materials

Steel consumption for all artillery and small arms has been generously estimated by the Ministry of Economic Warfare at 850,000 tons a year. This is under 3 percent of annual German steel output - clearly not a severe drain upon steel capacity. Ammunition production consumes

somewhat larger amounts of steel, but still not in significant proportions. Some copper, on the other hand, is used in the production of AA ammunition. Nickel is believed to be the only other raw material consumed in any important quantities in AA artillery and ammunition manufacture. The German nickel supply is tight, and employment of nickel for gun production has probably resulted in a qualitative deterioration in other armament items.

V. SUPPLY AND REQUIREMENTS OF THE GROUND DEFENSE SYSTEM

A. Requirements

Absolute requirements for German ground defenses are, for all practical purposes, unlimited. These requirements may be defined as sufficient AA strength to make United Nations bombing raids excessively costly in terms of results achieved. Defenses of the great magnitude necessary to fulfill these requirements are clearly beyond the present or future capacity of the German AA artillery industry.

Relative requirements, defined as the AA strength necessary to maintain a fixed relationship between defensive opposition and Allied bomber raids are rapidly expanding with the passage of time. The RAF night area-bombing offensive has been considerably accelerated both in weight and intensity of attack in the past two years. In addition, American daylight bombing operations from the British Isles are multiplying Germany's defensive requirements by obliging Germany to defend new targets and by occupying the defending forces on a twenty-four hour basis.

These relative requirements may confidently be expected to expand substantially in the future. RAF and USAAF attacks from the British Isles are continually increasing in range and intensity. Acquisition of bases in

Italy will require heavy defenses of cities in Central, Southern, and Eastern Germany and Austria, which have hitherto enjoyed relative invulnerability. Finally, as German fighter strength dwindles, greater responsibility for the protection of German cities will rest upon the ground defenses.

B. Supply

1. Present Position. Germany's present extensive holdings of AA guns have been accumulated over the period of a number of years of large-scale production. Wastage, with the exception of gun barrels, has always been a negligible factor for guns deployed in rear area defenses. In addition, German gun models have become relatively standardized, and obsolescence has not achieved any degree of importance. Monthly output of AA guns, for these reasons, comprises only a small proportion of total strength. As a result, each monthly increment of new production makes a relatively slight contribution to overall defensive capabilities, although in the course of a year an increase in strength in the neighborhood of 25 percent could be made.

Ammunition, on the other hand, is a rapidly expendable item. It seems reasonable to assume that stockpiles of critical ammunition parts, such as fuses, have existed in the past. Germany probably did not anticipate the scale of bombings to which it is now being subjected, however, and it is likely that these reserves are being heavily drawn upon. These assumptions are substantiated by ground intelligence reports, which refer to a shortage of AA ammunition and state that a policy of conservation has been instituted. Although these shortages may, so far, only prove to be

local in character, there is reason to believe that the ammunition supply position is becoming somewhat strained.

Deficiencies in the supply of trained personnel have already been noted. Maintenance of the present scale of defensive effort has apparently necessitated the widespread recruitment of less-skilled civilians for service in Heimatflak batteries. The increase in the size of heavy-Flak batteries of from four to six guns may also be interpreted as evidence of the need for economy in the use of operating personnel.

The supply of radio-detection equipment, and particularly of radio fire-control apparatus, is clearly not as abundant as present GAF dispositions would require. Bomber crew reports and photographic intelligence reveal that radio fire-control equipment is gradually coming into more frequent use. However, alternative methods of fire control have always been used, so that this shortage represents the postponement of a qualitative improvement rather than a restriction upon present AA gun fire. Reformation of batteries on the basis of six rather than four guns, moreover, introduces economies in the use of existing radio equipment.

2. Possibilities of Future Expansion. Considerable productive plant for gun and shell manufacture was seized by Germany with the conquests of Poland, Czechoslavakia, and France. The plants themselves have, by and large, remained idle or are being used for repair work or manufacture of spare parts, although some machine tools have probably been transferred to other industries. In addition, conversion within the artillery industry is a relatively simple task. In view of the known high priority which attached to AA gun manufacture, this conversion could probably take place

if all other resources necessary for expanded AA production were available. While machine tools, skilled labor and critical raw materials are not abundant, it is doubtful if these factors alone would impose insuperable restrictions upon an expansion of artillery production.

The existing shortage of trained manpower for AA gun crews undoubtedly places restrictions upon increases in the production of new weapons. Additional manpower can be made available by the use of over-age civilians, ex-servicemen, youths of 16 and 17, and possibly women. Foreign laborers have never been used, as far as is known, since Germany probably does not place sufficient confidence in them. Any further recruitment of personnel from these sources, however, would result in a definite deterioration in the accuracy of Flak fire. While regroupment of batteries into six-gun rather than four-gun positions would provide further economies in the use of operating crews, this increase would result in a less economical deployment of the guns themselves.

Fuse requirements for AA ammunition impose a heavy burden on Axis productive facilities for this precision equipment. Switzerland is a major source of Axis supply for precision clockwork fuses used in heavy AA fire, although German fuse capacity has probably been enlarged since the outbreak of war. It may be assumed that both Swiss and German fuse manufacturers are operating at full capacity and are incapable of any considerable expansion in the short run. It has previously been assumed that stockpiles of fuses and other ammunition parts are now being depleted, due to the rapid turnover in ammunition and Germany's inability to anticipate fully the present scale of Allied bombings. In this event, shortages of ammunition may well limit the possibilities of an expansion of the ground defense system.

Although the radio industry is probably operating at full capacity, it seems probable that optical fire-control instruments could be made available in whatever quantities are necessary for further gun production. The radio industry, however, should meet with difficulties in equipping the areas which will become exposed to attack from North Italy with sufficient detection equipment.

C. Conclusion

Requirements of the ground defense system, related to the weight and intensity of Allied bombings and the extent of the area to be defended, are clearly increasing. Present monthly output is believed to make only a relatively small contribution to overall gun deployment and defensive capabilities. The limitations to a further expansion of the AA defenses in the face of increasing requirements, are probably set by a shortage of trained operating personnel and by a shortage of ammunition, particularly fuses. There are evidences that the defensive position may be becoming somewhat strained, and incapable of any considerable expansion. German defensive capabilities certainly cannot increase so rapidly as Allied offensive air operations would require. There is still no reason to doubt, however, that the German ground defenses will continue to provide considerable opposition to American and British bombing raids.

In view of the increasing importance which will be attached to the ground defenses in the event that GAF fighter strength declines, it is recommended that further consideration be given to the Axis fuse and ammunition industry, with particular emphasis on an appraisal for bombardment purposes.

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